College of Arts and Sciences, Atmospheric Sciences Program

Exploring Mixed Boundary Layer Heights: The Impact of Latent and Sensible Heat Fluxes Through the Bulk Aerodynamic Method

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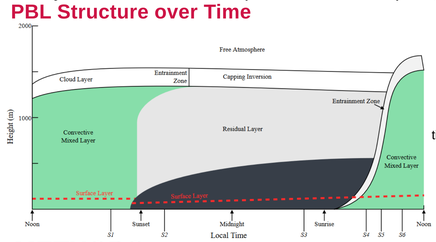
INTRODUCTION

The planetary boundary layer (PBL) directly interacts with the Earth's surface and is affected by turbulent mixing processes. The mixing height of the PBL is influenced by several surface-atmosphere fluxes, including:

- **Sensible heat flux (Q_H)**: The vertical exchange of heat due to temperature differences between the surface and the atmosphere [4].
- **Latent heat flux (Q_E)**: Heat exchange during the phase change of water involving the release or absorption of heat without a change in temperature [6].

This project aims to investigate the correlations between PBL height and the surface heat fluxes. Using surface measurements and the bulk aerodynamic method to quantify the fluxes, this study explores how heat exchanges may influence PBL heights (PBLH). Understanding these fluxes is essential for accurate weather predictions and comprehending severe storm dynamics. Improved knowledge of this relationship will also enhance our ability to forecast weather patterns and air quality.

PBL Structure over Time



This image illustrates the time-dependent structure of the PBL [7].

METHODS

The bulk aerodynamic method provides a simple, cost-effective, and widely applicable way to measure heat fluxes between the Earth's surface and the atmosphere, using readily available sensors and real-time data. This method is less demanding in terms of instruments but relies on empirical formulations that may not fully capture the intricacies of turbulent transfer processes potentially affecting accuracy [5]. Oke (1978) modified the original equations by applying stability corrections resulting in:

- $Q_H = -\rho C_p k^2 z^2 \left(\frac{\Delta\overline{u}}{\Delta z}\frac{\Delta\overline{\theta}}{\Delta z}\right)(\Phi_M\Phi_H)^{-1}$
- $Q_E = -\rho L_v k^2 z^2 \left(\frac{\Delta\overline{u}}{\Delta z}\frac{\Delta\overline{q}}{\Delta z}\right)(\Phi_M\Phi_H)^{-1}$

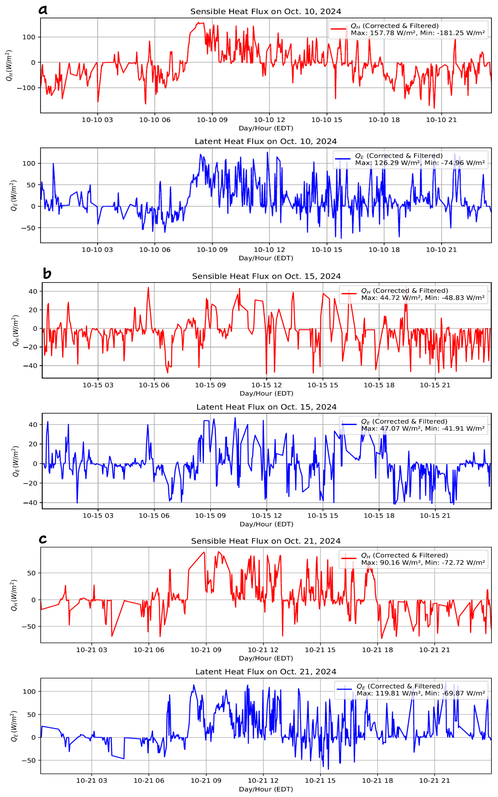
For quantification of mixing in the PBL, the vertical profile of potential temperature (θ) was analyzed. For a well mixed PBL, the vertical profile exhibits little to no change in θ (uniformity with height) until reaching the temperature inversion layer [1]. θ was quantified as

- $\theta = T\left(\frac{P_0}{P_1}\right)^{R/c_p}$

RESULTS

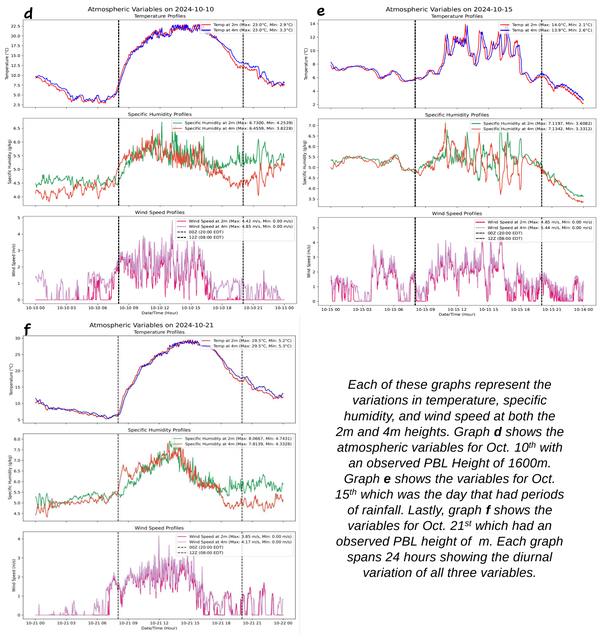
Although Oct. 8th, 10th and 16th had highest observed PBL heights, the temperature and specific humidity maxima were larger for the lower height days. This indicated that wind speed may have been the primary factor for influencing the overall PBL heights which has been shown in prior studies [3]. Over the lower PBLH days, winds speeds overall were slower than on the higher PBLH days. Analysis of the rainfall event, the observed PBLH was unclear **(h)** indicating little to no mixing occurred during the event. The higher PBL days had slightly larger fluxes **(a)** compared to the lower PBL days **(c),** however, the rain day had the lowest fluxes **(b)** which can be attributed to the suppression of mixing due to rainfall's effects on temperature and wind speed **(e).**

Variations of Heat Fluxes



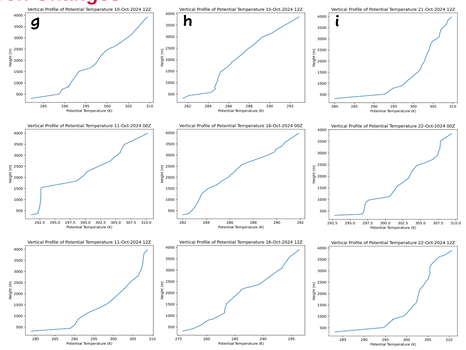
*Graph **a** depicts the changes in Q_H and Q_E over a 24-hour period for the day with the highest observed PBL heights of (1600m). Graph **b** shows the same changes with intermittent periods of rainfall over 24-hour period (~1400m). Graph **c** shows same changes over 24-hour periods on the day with the lowest observed PBL heights (1000m).*

Corresponding Temperature, Specific Humidity, & Wind Speed Profiles



*Each of these graphs represent the variations in temperature, specific humidity, and wind speed at both the 2m and 4m heights. Graph **d** shows the atmospheric variables for Oct. 10th with an observed PBL Height of 1600m. Graph **e** shows the variables for Oct. 15th which was the day that had periods of rainfall. Lastly, graph **f** shows the variables for Oct. 21st which had an observed PBL height of m. Each graph spans 24 hours showing the diurnal variation of all three variables.*

Variation in PBL Heights: Maximum, Minimum, & Rain Driven Changes

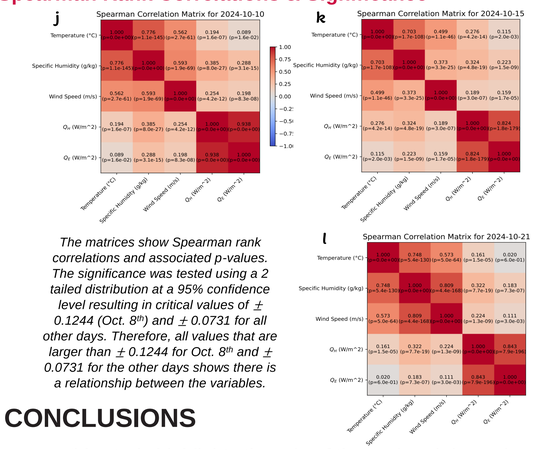


*These are vertical profiles of θ depicting evolution of PBL heights. Column **g** represents the evolution for one of the highest observed PBL height, column **h** shows height evolution during rainfall, and column **i** shows evolution for one of the lowest observed PBL heights.*

Statistical analysis showed significant correlations on most days, with weaker or no significance generally associated with temperature and Q_E and once with Q_H on the 11th. Wind speeds on the 19th did show an inverse relationship with both Q_H and Q_E , however, the correlation was still significant since it fell within the critical value threshold.

Lastly, specific humidity on the 8th showed the correlation may have been due to random luck, however, the weak correlation could have been due to lack of a full day's dataset. Other studies found higher correlations, with use of longer-term dataset (decadal) coupled with the partial derivative approach [2]. Studies have also shown that wind speeds contributed largely to mixing within the PBL [3]. These findings align with previous work, though more studies are needed to explore the spatial impacts of individual heat fluxes on PBLH.

Spearman Rank Correlations & Significance



The matrices show Spearman rank correlations and associated p-values. The significance was tested using a 2 tailed distribution at a 95% confidence level resulting in critical values of $\pm$ 0.1244 (Oct. 8th) and $\pm$ 0.0731 for all other days. Therefore, all values that are larger than $\pm$ 0.1244 for Oct. 8th and $\pm$ 0.0731 for the other days shows there is a relationship between the variables.

CONCLUSIONS

This study highlights the role of thermal and dynamic processes in PBLH behavior. Wind speeds showed to enhance mixing during the day but had less impact at night when the PBL stabilized. Higher PBLH lead to stronger correlations between temperature, wind, and fluxes, while lower PBLH resulted in weaker correlations due to reduced mixing. The rainfall event showed that it may suppress PBLH due to its effects on thermal and wind profiles. These findings provide a foundation for understanding the heat fluxes and their influence on PBLH. Future studies that incorporate more rainfall events and continuous PBLH measurements could prove valuable for further clarifying these relationships and improving our understanding.

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